NAGW-1651

"Development of Large Area of Emulsion Chamber Methods with a Superconducting Magnet for Observation of Cosmic Ray Nuclei from 1 GeV to 1,000 TeV"

ANNUAL REPORT

March 1, 1993 - February 28, 1994

Submitted to

NASA Headquarters
Contracts and Grants Division
Washington, D.C. 20546

Prepared by

Dr. Yoshiyuki Takahashi
Principal Investigator

Submitted by

The University of Alabama in Huntsville
Huntsville, Alabama 35899

March, 1994

SUMMARY OF THE SECOND-YEAR RESEARCH WORK

1. Duration of the research of the present report: 3/1/93-2/28/94

2. Summary of the proposal:

2 - 1 The Scope of the Investigation

The direct observation of very high energy cosmic rays at energies above 100 TeV is crucial in understanding the nature of elemental composition and its origin at the main transition energy region of cosmic particles where the all-particle spectrum is known to bend ("knee") drastically. There are significant technical limitations in realizing direct observations above 100 TeV. Conventional methods to measure particle energies do not work above 100 TeV. For example, Cerenkov radiation methods cannot be applied to the particles above several hundred GeV/n, and transition radiation signals saturate above 10 TeV/n, while total absorption calorimeter requires hundreds of tons of absorber materials that cannot be carried to space. The emulsion chamber method has been the only viable method so far. However, it also requires to increase the payload weight to extend the measurements beyond 1,000 TeV.

The present research program focus the efforts in developing new techniques in measuring high energy cosmic ray nuclei with nuclear emulsions. First of all, we utilize the highest energy accelerator heavy-ion beams at CERN, and calibrate the energy measuring methods of the emulsion calorimeter that has been used in balloon-borne emulsion chamber experiments by the Japanese-American-Cooperative-Emulsion-Experiments (JACEE). This method utilizes the inelasticity distribution of hadronic collisions, and allow measurements of the energy release into neutral pions, which allows the primary energy spectrum measurements to ±20%. We improve the calorimetry further by measuring the energies of charged particles in magnet field, in addition to those of photons (neutral pions). A new detector, the Magnetic-Interactive-Emulsion-Chamber (MAGIC), has been introduced for this purpose as well as for the detailed study of nucleus-nucleus interactions. This MAGIC detector also permits particle identification of secondary charged particles up to 100 GeV/c for the study of the secondary particles. Another new detector in magnet field, Beam Tracker (BT), has been designed, with which all the heavy nuclei ($Z > 6$) in CR-39 plates from balloon-borne magnetic emulsion chambers can be traced automatically with CCD and will be measured for primary charge and momentum (up to 1 TeV/n). Tracking software must be developed and tested for future flights with a super-conducting solenoid magnet.

New techniques are to be investigated in the present program. Among them, the electron-pair method is promising to permit a direct measurement of the high energy nuclear tracks in emulsions, by the measurements of the number of electron-pairs emanating from the track. It is theoretically predicted that about 100 pairs will be seen in only 3 cm-long track of iron nucleus when its energy is higher than 10 TeV/n. We calibrate this cross section by using the heavy ion accelerators so that its application can become reliable for cosmic ray tracks. In principle, this method will allow direct energy measurements of individual nuclear tracks above 1 TeV/n up to 10,000 TeV/n.

Several new methods with nuclear emulsions for track-image analysis have been examined in order to measure momentum, electric charge and Lorentz Factor of high energy primary cosmic ray nuclei and secondary particles.

The second year tasks were (1) further measurements of direct electron-pair production with accelerator beams, (2) Continuing tracing and measurements of high energy cosmic nuclei events in the JACEE-7 and JACEE-8 long-duration balloon flight emulsion chambers, (3) Automatic morphometry of delta-rays for cosmic nuclei and 200 GeV/n accelerator beams, and (4) improve the emulsion calorimeter method for faster charge identification and energy measurements. Instrumentation required are a workstation (SUN SPARC 2) and software transfer for UNIX.

2 - 2. Progress Made During the Second Year

Calibration experiments of particle tracking in magnetic field were performed with 200 GeV/AMU sulphur beams and with 490 GeV muons. About 3.5 meters of muon tracks were so far scanned. Measured cross sections with heavy ion beam tracks are summarized and accepted for publication in the Physical Review. Presently, the all the measured data are consistent to the most accurate higher-order QED calculations made by P.B. Eby (1991; Phys. Rev. A43, 2258), and Nikishov and Pichkurov (1982; Sov. J. Nucl. Phys., 35, 561). This successful calibration of basic cross section confirms a prospect of using pair counts for determining energetic cosmic ray nuclei above 10 TeV/n up to over 1,000 TeV/n. The method was originally proposed in 1985 by Y. Takahashi et al (Proc. Workshop on Cosmic Ray and High Energy Gamma Ray experiments for the space station Era, LSU Press, p. 390), and was proposed for the GOAL program (RBE) committee in March 1992.

Analysis of the composition of high energy cosmic ray nuclei has been advanced, and the summary of the results was reported in the 23rd International Cosmic Ray Conference, Calgary. Scanning and tracing of lower energy events have been made with all blocks of emulsion chambers (JACEE 7 and 8) to reduce the detection

threshold energy, and 100% of subjected events were traced with 100% efficiency. This analysis was made to see the proton spectrum further around the deficient energy region (a possible bend at 50-80 TeV). By the end of March 1993, the analysis was completed, which gav an additional statistics to confirm the spectral shape (with about 100 more events at the energy region 30 - 80 TeV).

In these measurements and analysis we developed CCD measurements of delta-range spectrum for the charge measurements of the primary tracks. All the primary charged were measured by us, by using the CAVIA microscope system of the University of Alabama in Huntsville. A new and fast energy measuring method in emulsion calorimeter was also developed, which gives the total photon energy in the calorimeter by simply measuring the radii of a fixed electron density for cascade showers. These new techniques developed by the present research program were reported in the GOAL Workshop and in the regular sessions in July, 1993, at the 23rd International Cosmic Ray Conference, Calgary.

From April 1993 to February 1994, two further measurements have been continuing. The primary gamma ray spectrum is being examined, and a method to eliminate those arizing from the atmospheric interactions is advanced. The latter uses the correlation of two or more gamma-rays detected in the emulsion chamber. Up to the enrgy region of 10 TeV, this method can remove gamma-rays originating from nuclear interactions to 20 km above the detector. This will practically remove almost all the background gamma rays from the analyzed datafor the study of galactic gamma rays. The work will continue in the third year. The much lower energy proton spectrum is being studied by reducing the detection thershold energy further down to 100 GeV. This work will also continue in the third year.

A designing and production of the emulsion chambers (two of 1.2 m **2 detectors) were made for the Antarctic balloon experiments of the JACEE for the 93-94 expedition. This is the detector scale almost equivalent to the planned GOAL experiments.

A new super-conducting magnet (10 Tesla) was built and completely tested in the second year, by the help of National Laboratory for High Energy Physics (KEK), Japan. The calibration experiments for the ionization measurements in a strong magnetic field is re-scheduled for June, 1994. Beam exposures to calibrate -dE/dx vs. momentum diagram will be made at KEK PS beam lines.

An automatic microscope system has been upgraded by adding a SUN SPARK 2+ Workstation. Automatic tracking programs originally written in FORTRAN for PC were transferred into UNIX. Automatic tracking/tracing programs (AUTOTRACK 1, 2 and 3) were planted in the SUN SPARC-2. An effort to automates measurements of delta-ray range spectrum for charge determination of cosmic ray nuclei

was initiated by using CUE-2 Densitometer program for CCD frame images. Also, the automatic curvature measuring software for CR-39 measurements were coded.

2 - 3. Plan of Work In the Third Year (3/94 - 2/95)

Measurements will continue on direct-pair production, long-range delta rays, particle tracking in magnet field, and cosmic ray composition. Experiments to calibrate the ionization rate for particle identification will be carried out by using a 10 Tesla super-conducting magnet around June, 1994. Tasks will include further upgrading of softwares and the host computer for the automatic microscope.

2 - 3 - 1. Emulsion exposures.

The following experiments are planned:

- June, 1994: p-bar and pi-minus beams at KEK PS.
- September, 1994: Test balloon flight experiment with a Superconducting Magnet and Beam Tracker.
- Winter 1994 - 95: an antarctic balloon flight (JACEE-13) with an emulsion chamber incorporated a pairmeter stack will be made.

Requests of cosmic ray balloon flights of emulsion chambers for very high energy cosmic ray composition measurements will be submitted by the NASA/MSFC collaborators for the JACEE experiments:

2 - 3 - 2. Measurements.

Grain-density counts of pions and protons (100 MeV - 10 GeV) will be made with emulsions in 10 Tesla magnet after the planned beam exposure at KEK PS (Japan). We continue measurements on cross-sections of long-range delta-rays and electron-pairs, utilizing previously exposed emulsions. The JACEE emulsion chamber analysis will continue further, to increase statistics of nuclei events near the detection threshold energy (1 TeV/n), by using the emulsions from the balloon flight successfully performed in 1993-94 in Antactica. Development of hardware and softwares for particle tracking in emulsion chambers will continue.

2 - 3 - 3. Design Studies and Operation of An Automatic Measurement System.

The study to operate a work-station (SPARC 2) in tandem the automatic microscope system (CAVIA) will continue in 1994, particularly, for the purpose of auto-tracking with Beam Tracker (BT) and electron-pairmeter.

Preparation for super-conducting magnet flights for 1994 - 96 will continue in 1994. A test balloon flight is scheduled for September, 1994. We are assisting engineering team of NASA/MSFC (Parnell et al.) for preparations and design study of the ground support equipment and gondola for balloon flights of super-conducting solenoid magnet.

3. Publications and Presentations:

Journal Publications

1. "Direct Production of Electron-Positron Pairs by Relativistic Oxygen and Sulfur Ions in Nuclear Emulsion," J.H. Derrickson, P.B. Eby, K.H. Moon, T.A. Parnell, D.T. King, J.C. Gregory, Y. Takahashi, T. Ogata, Phys. Rev. A accepted, 1993.

2. "Multiple Photon Emission in Heavy Particle Decays". K. Asakimori, T.H. Burnett, M.L. Cherry, M.J. Christl, S. Dake, J. H. Derrickson, W.F. Fountain, M. Fuki, J.C. Gregory, T. Hayashi, R. Holynski, J. Iwai, A. Iyono, W.V. Jones, J.J. Lord, O. Miyamura, H. Oda, T. Ogata, E.D. Olson, T.A. Parnell, F.E. Roberts, S.C. Strausz, Y. Takahashi, T. Tominaga, J.W. Watts, J.P. Wefel, M. Wilber, B. Wilczynska, H. Wilczynski, R.J. Wilkes, W. Wolter, E.L. Zager, submitted to J. Phys. G. (1994).

Publications in Conference Proceedings

3. "Results from JACEE and EMU05," Y. Takahashi, AIP Conference Proceedings 276, pp. 275 - 291, 1993.

4. "Cosmic Ray Composition and Spectra: (1). Protons," K. Asakimori et al., (The JACEE Collaboration), Proc. 23rd International Cosmic Ray Conf., Calgary, 2, 21 (1993).

5. "Cosmic Ray Composition and Spectra: (2). Helium and Z > 2," K. Asakimori et al., (The JACEE Collaboration), Proc. 23rd International Cosmic Ray Conference, 2, 25 (1993).

6. "Direct Electron Pairs Along Heavy Ion Tracks," J.H. Derrickson, P.B. Eby, W.F. Fountain, T.A. Parnell, J.W. Watts, K.H. Moon, D.T. King, J.C. Gregory, Y. Takahashi, T. Ogata, Proc. 23rd International Cosmic Ray Conf., Calgary, 2, 540 (1993).

7. "Charged Particle Spectra and Isospin Clusters in S + Pb Interactions at 200 GeV/amu," A. Iyono, Y. Takahashi, C.H. Chan, P.C. Gregory, T. Hayashi, T. Shiina, M.J. Christl, B. Rubin, J.H. Derrickson, W.F. Fountain, T.A. Parnell, J.W. Watts, S. Nagamiya, T. Tominaga, S. Sake, M. Fuki, T. Ogata, S. Miyamura, H. Yokomi, Proc. 23rd International Cosmic Ray Conf., Calgary, 4, 13 (1993).

8. "Multiple Photon Emission in Decays of Particles Produced in Cosmic Ray Interactions," H. Wilczynski et al., (The JACEE Collaboration), Proc. 23rd International Cosmic Ray Conf., Calgary, 4, 29 (1993).

9. "Core-Size of Very High Energy Cascades in Emulsion Chambers," Y. Takahashi and M. Fuki, Proc. 23rd International Cosmic Ray Conf., 4, 159 (1993).

10. "Flux of Strange Matter on Supersonic Concorde," Y. Takahashi and J.N. Capdevielle, Proc. 23rd International Cosmic Ray Conf., Calgary, 4, 654 (1993).

11. "Tickling the Knee with JACEE," K. Asakimori et al., (The JACEE Collaboration), Proc. 23rd International Cosmic ray Conf., Calgary, 4, 708 (1993).

12. "Detection Efficiencies of Very High Energy Particles in Emulsion Chambers," M. Fuki and Y. Takahashi, Proc. 23rd International Cosmic ray Conf., Calgary, 4, 730 (1993).

Presentations

1. "Energy Spectra and Composition of Cosmic Rays up to 100 TeV Observed by JACEE Balloon Flights," Y. Takahashi, Highlight session, 23rd Int. Cosmic ray Conf., Calgary, July, 1993.

2. "New Measurement Methods of High Energy Nuclei and Their Interactions with JACEE Emulsion Chambers for GOAL," Y. Takahashi, The GOAL Workshop, 23rd International Cosmic Ray Conference, Calgary, July, 1993.

3. "Cosmic Ray Composition and Spectra: (1). Protons," (The JACEE Collaboration), 23rd International Cosmic Ray Conf., Calgary, July (1993).

4. "Core-Size of Very High Energy Cascades in Emulsion Chambers," 23rd International Cosmic Ray Conf., July (1993).

5. "Flux of Strange Matter on Supersonic Concorde," 23rd International Cosmic Ray Conf., Calgary, July (1993).

1. Personnel.

The scientific staff, Y. Takahashi, J. C. Gregory and T. Tominaga, have been working with, and supervising the work of, a laboratory technician, B. L. Dong, and full-time graduate students, T. Ghiina, K. Chevli, and J. Johnson. A part time graduate student, M. J. Christl, has worked in particle tracking. We supervised another full-time graduate student, M. Tocci, who started research work in modification of emulsion calorimeter by using scintillation fibers and micro-channel plate. Considering the increase in student salaries, we have had to sacrifice some of the senior personnel salaries. We are still severely limited in funding for man-power.

[CAVIA AUTO-TRACK ANALYSIS SYSTEM AT UAH, 1993]